

OBSERVATIONS OF WAVES AND CURRENTS NEAR THE SURF ZONE

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LONG-TERM GOALS

The overall goal is to understand the form and dynamics of the flows near shore. These flows are forced by waves, wind, pressure gradients, stratification, and (perhaps) Coriolis, and are strongly modified by topography. Given the forcing and topography, I would like to be able to predict the flow regime, in terms of the occurrence and strength of instabilities and rip currents, and the net effect on horizontal mixing and diffusion.

OBJECTIVES

The first objective is to classify the various flow conditions observed at SandyDuck in terms of some (as yet to be rigorously defined) measures of the nonlinear regime of the flow. Two complementary approaches are in terms of (1) the occurrence and strength of "rip currents" (narrow jet-like current structures extending more or less continuously from shore) and (2) the occurrence and strength of "shear waves" (instabilities associated with the alongshore flow especially along the crest of a sandbar). The next objective is to related these classifications to the forcing, in order to determine the important parameters controlling the flow. The final objective is detailed comparison and refinement of models of nearshore flow, in order to refine our understanding of the links between forcing and flow.

APPROACH

The first step is to define objective measures of the flow regime that are useful yet practical. For example, some recent work [*Slinn et al.* 1998] has usefully characterized the flow regime in terms of what I would call a horizontal bulk Reynolds number: the ratio of (bottom) frictional to (horizontal) advective time-scales (which they call "Q"). However, reverse-engineering of "Q" from the observed velocity fields is uncertain and probably not really practical. The approach taken here is to examine averaged indicators of flow activity. For example, the average enstrophy (mean square vorticity) should be a good indicator of the occurrence of shear waves; in contrast, the kinetic energy (mean square velocity perturbations) over 1 to 10 minute periods should be a good indicator of the total flow perturbations, including both rip currents, shear waves, and other infragravity motions. Further analysis via time-space Fourier transforms may permit separation of motions according to the appropriate dispersion relations.

On the technical side, a significant requirement is verification and calibration of the phased-array Doppler sonar (PADS) measurements. The existing model for transforming the "raw" acoustic data into maps of velocity and scatterer density is adequate to begin concurrent work on the above objectives. However, new obstacles to be considered and overcome include partial backscatter from the

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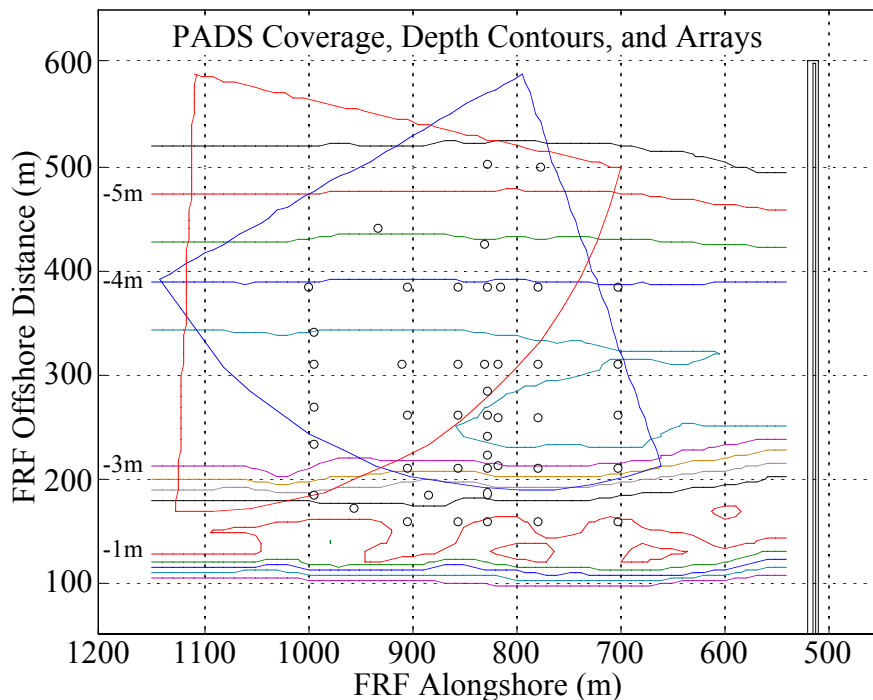


Figure 1. SandyDuck experimental site, showing the maximum areas covered by the Phased Array Doppler Sonars (PADS). The circles show locations of frames with current meters (etc.) near or in the area. North is about 20° clockwise of left. The location is the Field Research Facility of the US Army Corps of Engineers, in Duck, North Carolina.

bottom and interference from acoustically bright structures. An exciting development in the use of these sonars is achieving the time-space-velocity resolution necessary to resolve the energy-containing surface waves. Questions concerning whether or not there is variation of the response in space and time (due, for example, to clouds of bright scatterers drifting over a relatively constant background of bottom-returns) can be addressed directly by examining surface waves as they propagate over well-known topography and currents. In addition to these "self-consistency checks," data from discrete locations within the PADS viewing area are being used for direct comparisons. Where there is strong vertical mixing, currents near the bottom can be used (e.g., Guza et al and Hay et al); at other times, the comparison is restricted to the smaller number of measurements taken through the water column (e.g., P. Howd).

WORK COMPLETED

Two "Phased Array Doppler Sonars" (PADS) were deployed in 6 m water depth as part of a major near-shore experiment in 1997, "SandyDuck" (figure 1). The instruments were successfully operated for two months almost continuously, retrieved essentially undamaged, and are now in storage. Each PADS measured radial velocity over a wedge up to 450 m radius by 90 degrees, with 6 m to 20 m 2D cell resolution. In the overlapping region, both horizontal components of flow can be deduced. The data resolve both surface-wave motion (with 1.5 second sampling), and lower frequencies (with 1-minute averages sampled every 30 seconds).

Software to combine the data from the two PADS was operational by mid-October 1997, and has been refined since then to incorporate dynamic estimates of the signal-to-noise levels, permitting the viewed

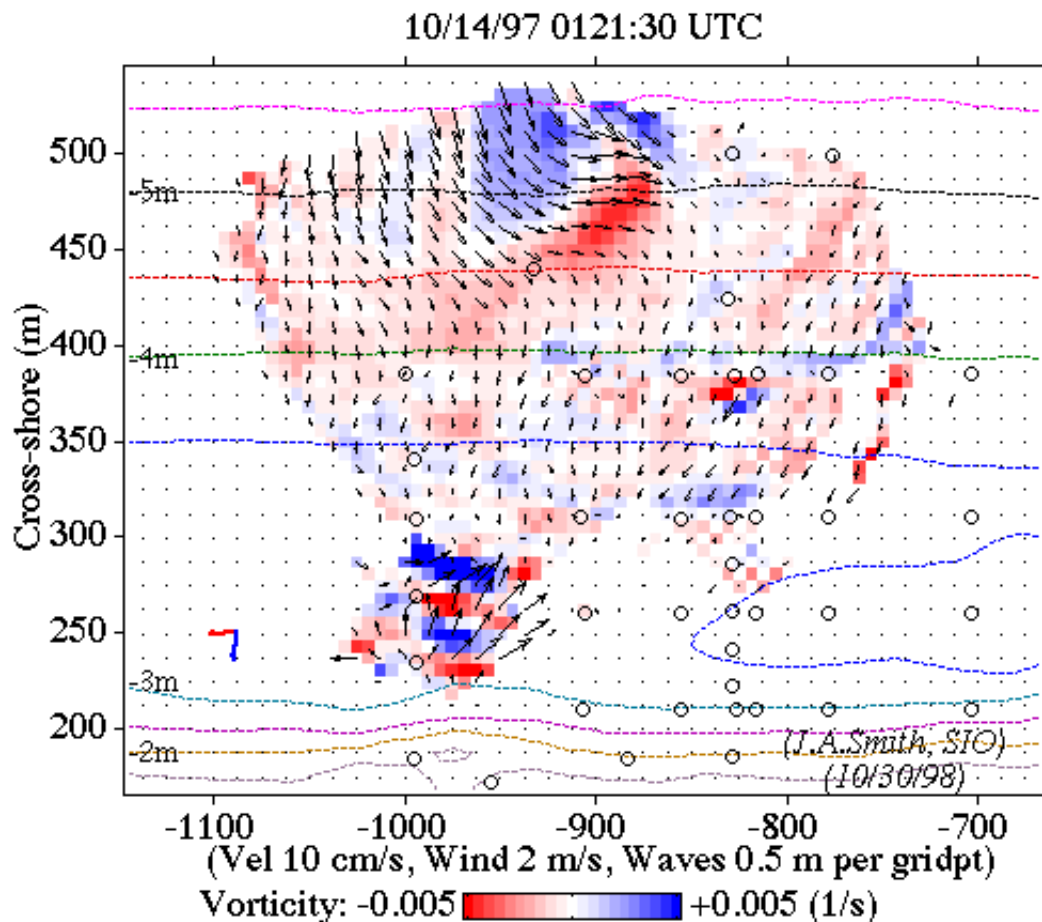


Figure 2. Horizontal velocity vector estimates (small black arrows) and the associated field of vorticity (color contours), estimated over the area covered by both PADS. Two features are observed: The upper feature resembles a “vortex pair” as sometimes seen in models. This moves through the domain from left to right, roughly along the 5-m contour. The strength of the feature is fairly constant, and it appears to leave behind a “trail” of red (-) vorticity along the -4.5 meter depth contour. The lower feature appears to be a rip current, probably originating near the gap in the sandbar. This “rip current feature” extends some distance into the domain, but fades quickly (within minutes). Response is uncorrected in this figure, so artifacts are visible around many of the array frames (denoted by circles). Red arrow at lower left is the wind speed (2 m/s) and direction, blue arrow is significant wave height (0.5 m) and direction. Note that the offshore flow opposes both wind and wave directions alongshore. [see movie at <http://jerry.ucsd.edu/vort1014.MOOV>]

area to vary in time as the good data retrieved varies. Additional refinements include the ability to compute and view the vertical component of vorticity and the horizontal divergence fields. The data are well behaved, so spatial derivatives can be taken; for the lower frequency data, sensible-looking vorticity estimates can be made. “External data” such as the wind speed and direction, wave height and direction, tidal elevation, and bottom contours are time-coordinated and incorporated into the plots. Coordinated elevation and bottom contours permit calculation of the “transport divergence” and potential vorticity from the estimated 2D velocity fields. Work on the verification and calibration of the instruments, a notoriously “invisible yet time-consuming” endeavor, is well underway.

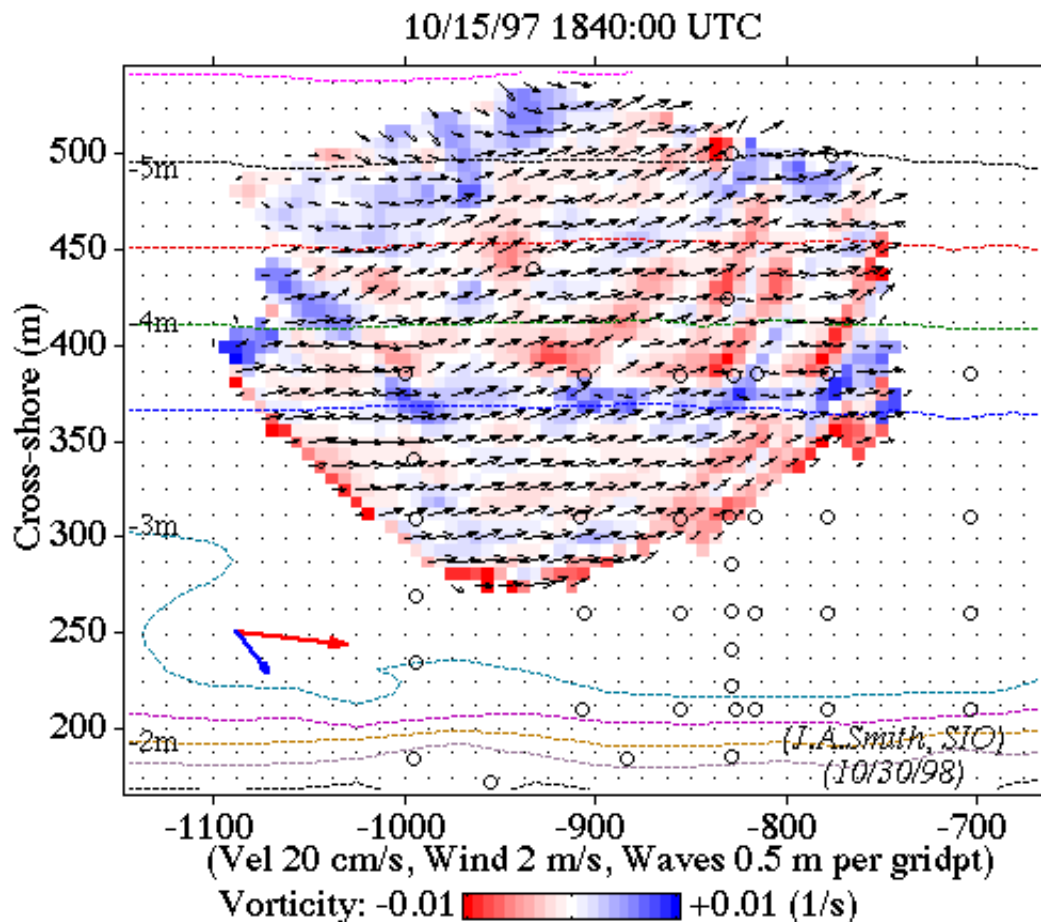


Figure 3. An example "frame" from a time of stronger forcing. Red arrow indicates windspeed (about 9 m/s) and direction, Blue arrow indicates significant wave height (about 1 m) and direction. In spite of the stronger forcing relative to figure 2, there are fewer features apparent in the flow field. The features seen here appear to be linked to array reflections, remaining fixed in space rather than advecting. Since most variance is steady, time-space Fourier analysis may help isolate the motion of interest. [see boring movie at <http://jerry.ucsd.edu/vort1015.MOOV>]

A "first pass" analysis of the data has been completed, thanks in part to the help of summer intern David Thompson, who worked here for 3 weeks prior to enrolling at U. Delaware this fall. This first pass included two distinctly different approaches: (1) 10-minute averaged fields were computed for a couple 4 to 5 day segments: September 17 to 21, and October 14 to 19, 1997. These both represent a transition from calm conditions through the first part of two moderate storms.

Internal dynamics versus boundary flux of vorticity can be addressed using estimates of velocity and vorticity near the edge of the region to estimate the boundary-flux of vorticity. There is a sense that the dissipation of vorticity should be larger where wave breaking occurs, and smaller further offshore. To make a first-cut examination of this, the measurement area was further subdivided into two parts, inshore and offshore of the 4 m depth contour. The notion that the near-shore vorticity dissipates much more rapidly than that offshore is born out in this calculation. In one particularly striking example, an offshore feature resembling a "vortex pair" propagates through along the 5 m contour, leaving behind a "tail" of negative vorticity; this remnant tail persists after the feature exits the other boundary, and decays with about a 20 minute time-scale. In contrast, the occasional offshore "squirts" associated with

rip-current activity (in the shallow sub-region) decay too rapidly to measure well, lasting only a few minutes. A first-pass survey of the data indicates that the former (a discrete offshore vorticity feature) is rare, while the latter (rip-current-like "squirts" coming off the inner bar) are sporadic but not uncommon.

RESULTS

Vortex generation and detachment apparently do occur near shore. While the former is probably quite common, persistence of through the latter appears to be rare. The early indications are that the highly nonlinear regime indicated by detaching vortex-pairs is more likely to occur during low winds and medium waves. The most striking example (figure 2) occurs during the unusual conditions of offshore flow opposing both wind and waves.

In wind & wave dominated conditions (figure 3) the Eulerian velocity has a distinct offshore component. In contrast, the Lagrangian drift, as indicated by the motion of bubble clouds (not shown here) is quite tightly shore-parallel. The difference would likely match the computed Stokes' drift of the waves [cf. *Smith* 1998]. This is apparently a significant term in the nearshore mass balance.

IMPACT/APPLICATIONS

One day it should be possible to predict the nonlinear regime of the flow: Will there be rip currents? How much on/offshore mixing may we expect? Are the conditions conducive to sediment transport? To build this ability, we need a data-base covering a variety of conditions, both in forcing and response, with sufficient time-space coverage to provide the needed measures of the flow.

The means by which we have viewed the velocity and vorticity fields in this study is novel. Patterns suggestive of vortex dynamics (e.g., a self-propagating vortex pair) have been observed in the nearshore environment for the first time. The PADS measurements are a natural complement to the discrete arrays of high-precision current meters, pressure sensors, (etc.) deployed within and near the surf-zone. As a data-base of conditions and response is built up, we can begin to extensively test our models and improve our predictive ability.

TRANSITIONS

Possible input to numerical models of both waves (e.g. FUNWAVE, J. Kirby) and nearshore circulation (e.g., Slinn & Allen, Dalrymple, etc.). Only in "preliminary talks" stage.

Beam combination technique has generated some interest in the CODAR community; preliminary talks on transitioning this algorithm are underway with L. Washburn and D. Fernandez.

RELATED PROJECTS

Proposed NSF project is aimed toward making this technology more accessible. Long-term ambition is to facilitate the use of such technology by other interested scientists.

Proposed acoustics project (ARL) would use a PADS to look upwards at the structure of bubble clouds in the open ocean (breaking waves), using it in a high-resolution short-range mode from FLIP (possibly intensity only).

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PATENTS

Paperwork toward patenting PADS technology has been registered.